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Stand-level effects of the mountain pine beetle outbreak in the central British Columbia interior

Chris Hawkins and Patience Rakochy

Mountain Pine Beetle Initiative Working Paper 2007–06

Mountain Pine Beetle Initiative Project # 8.23

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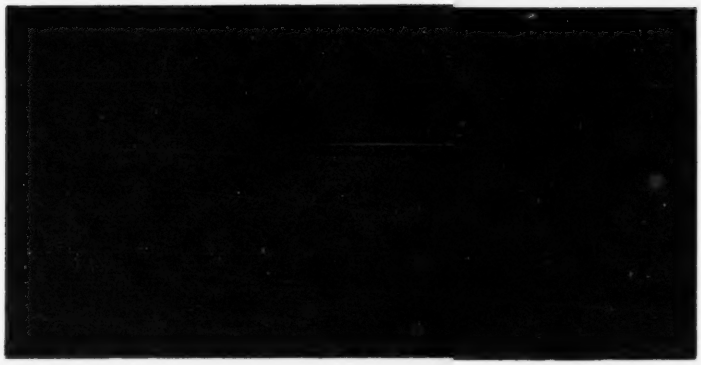

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Abstract

Pure pine stands were sampled in the Sub-Boreal Spruce biogeoclimatic zone (SBS) dry cool subzone; dk) in 2004 (48 stands, more than 300 plots) and pine-leading stands were sampled in the SBSdw2 (Blackwater dry warm subzone), SBSdw3 (Stuart dry warm subzone), and SBSmc3 (Kluskus moist cold subzone) in 2005 (74 stands, more than 370 plots) in the central British Columbia interior to document changes in stand characteristics of pine-dominated stands following mountain pine beetle attack and to assess the potential of stand development after beetle attack without management intervention. About 5% of trees less than 10.0 cm diameter at breast height were attacked, and attack rates greater than 80% were observed in trees with diameters at breast heights equal or greater than 20 cm. As stand densities increased, beetle attack rates decreased. Vigorous, widely spaced, young stands may be at a greater risk to mountain pine beetle attack than was previously believed.

The impact of beetle attack depended on the stands' species composition prior to attack. Pure pine stands in the SBSdk had post-attack mature stocking at minimum levels (542 stems per hectare (sph), of which 440 sph were pine), whereas pine-leading stands were well stocked (1078 sph, of which 760 sph were not pine). If mountain pine beetle attack continues in pure pine stands, they will not be stocked. There also was significantly less regeneration in pure pine stands sampled in 2004: 325 sph versus 2000 sph in the 2005 samples. Without management intervention, the stands in the SBSdk will likely not contribute to the mid-term timber supply, whereas stands from the SBSdw2, SBSdw3 and SBSmc3 potentially can contribute both to the mid- and long-term timber supply.

Keywords: mountain pine beetle, regeneration, advanced regeneration, stand dynamics, growth and yield, timber supply, modeling, historic range of variation

Résumé

On a échantillonné des peuplements purs de pins dans la sous-zone froide et sèche de la zone biogéoclimatique sub-boréale d'épinette (SBSdk) en 2004 (49 peuplements, plus de 300 placettes), ainsi que des peuplements majoritairement composés de pins dans la SBSdw2 (sous-zone sèche et chaude de Blackwater), dans la SBSdw3 (sous-zone sèche et chaude de Stuart) et dans la SBSmc3 (sous-zone humide et froide de Kluskus) en 2005 (74 peuplements, plus de 370 parcelles) dans le centre de la Colombie-Britannique, pour étayer les modifications des caractéristiques des peuplements majoritairement composés de pins après une attaque du dendroctone du pin et pour évaluer le potentiel de développement des peuplements après une attaque du ravageur sans intervention. Environ 5 p. 100 des arbres de moins de 10 cm de diamètre à hauteur d'homme ont été attaqués et on a observé des taux d'attaques supérieurs à 80 p. 100 sur les arbres d'au moins 20 cm de diamètre à hauteur d'homme. Les taux d'attaques du dendroctone étaient inversement proportionnels à la densité du peuplement. Les

peuplements jeunes, vigoureux et dispersés pourraient être menacés par une attaque du dendroctone bien plus que nous le pensons.

Les conséquences d'une attaque du dendroctone dépendaient de la composition du peuplement avant l'attaque. Les peuplements purs de pins dans la SBSdk avaient une proportion minimale de surface occupée par des arbres mûrs après l'attaque (542 troncs par hectare (tph), dont 440 tph de pins), alors que les peuplements composés majoritairement de pins étaient bien pourvus (1 078 tph, dont 760 tph d'espèces autres que du pin). Si le dendroctone continue d'attaquer les peuplements purs de pins, ceux-ci ne seront plus pourvus. La régénération des peuplements purs de pins échantillonnés en 2004 était également bien moindre : 325 tph contre 2 000 tph dans les échantillons de 2005. Sans intervention au niveau de la gestion, les peuplements de la SBSdk ne pourront peut-être pas contribuer à l'approvisionnement de bois à moyen terme, alors que les peuplements des SBSdw2, SBSdw3 et SBSmc3 pourront éventuellement contribuer à l'approvisionnement en bois à moyen et à long terme.

Mots-clés : dendroctone du pin ponderosa, régénération, régénération avancée, dynamiques des peuplements, croissance et production, approvisionnement en bois, modélisation, intervalle des variations antérieur

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1 Introduction

The lodgepole pine (*Pinus contorta* Dougl. Ex Loud. Var. *latifolia* Engelm.) forests of British Columbia (BC) are currently experiencing the largest mountain pine beetle (*Dendroctonus ponderosae* Hopkins) (MPB) outbreak since the arrival of European settlers (Eng et al. 2005). The BC Ministry of Forests and Range (MoFR) and licensees have been tracking the spread of the outbreak since 1995 (Rakochy 2005). It is predicted that by the end of the epidemic, 80% of the susceptible pine will have been killed (Eng et al. 2005) and the mid term timber supply in the Prince George timber supply area (TSA) will have fallen from a pre – MPB AAC (allowable annual cut) of 9.1 million m^3 to about 6.9 million m^3 35 years from today (Eng et al. 2005, Pousette 2006). The post MPB epidemic cut is based on several assumptions i) oldest attacked stands are harvested first, ii) only mature stands are affected with attack rates of about 80% in age class 5 and older and attack rates of about 50% in age class 4, iii) no attack in age classes 1 to 3, iv) regeneration delay of 15 years in areas not logged, and v) a shelf life of 15 years with 5 years for sawlogs (Eng et al. 2004, 2005). Also, the former BC Chief Forester has suggested that between 25% to 40% of the MPB killed timber would not be harvested (BC Ministry of Forests 2004a, b). Maintaining MPB attacked but stocked, older age class stands on the landscape may assist in minimizing the historic range of variation. An understanding of how these unlogged stands change (develop) over time is requisite for assessing the impending impacts on stand dynamics and potential mid-term timber supply. Changes will primarily be related to the MPB induced mortality in the stand (Hawkes et al. 2004, Stockdale et al. 2004) and abundance and condition of advanced regeneration (Heath and Alfaro 1990, Dale et al. 1998).

The current outbreak in the central BC interior has been attributed to i) increased annual temperatures of 1.1 °C (Ministry of Water Land and Air Protection 2002), ii) absence of extreme winter temperatures which have ended previous outbreaks (Cayer 1988, Caroll et al. 2004) and iii) the abundance of suitable (age class 5 and older) host - 1.2 billion m^3 of lodgepole pine on about 8.1 million ha (Eng et al. 2004, 2005). Amman (1978) suggested epidemic MPB populations develop when there is an expanse of mature pine greater than 80 years (age class 5), mean tree dbh (diameter at breast height) are > 20 cm, and significant numbers of trees have phloem thickness ≥ 2.5 mm. Interestingly, 'beetle proofing' a stand which increases inter tree spacing (Whitehead et al. 2004) results in increased mean tree dbh as well as enhanced tree vigor.

Mountain pine beetles prefer larger diameter, mature pine with the thicker phloem because it promotes successful brood production (Safranyik 1971, Shrimpton 1973, Shrimpton and Thomson 1985). Up to about 60 years (age class 3), the resistance of lodgepole pine to MPB increases and then declines (Safranyik et al. 1974), presumably as the trees develop thicker phloem. Thicker phloem generally produces more offspring (Amman 1972, Amman and Pace 1976). Mountain pine beetles, which emerge from smaller dbh trees, tend to be smaller than those which develop on large dbh trees (Sayranyik and Jahren 1970). At endemic levels, MPB tend to attack weakened trees but when the population reaches epidemic levels they will attack healthy trees (McGregor and Cole 1985).

The death of a tree has been attributed to the MPB larvae feeding on the phloem and the introduction of species (*Opiostoma clavigerum* (Roninson-Jeffrey and Davids) or *O. montium* (Rumbold) von Arx.) of blue stain fungi which disrupt water flow to the crown (Reid et al. 1967). The MPB, however, is more likely the vector of death rather than the direct cause, as pine trees die even in the absence of larval development after MPB attack (Safranyik 1985). Under non-epidemic conditions the MPB generally thins from above (Roe and Amman 1970) but under epidemic conditions the MPB can be a stand replacing disturbance (Shinneman and Baker 1997). When epidemic, the MPB tends to attack in waves with smaller trees being attacked in subsequent years (Amman et al. 1997, Stockdale et al. 2004). This suggests that unless all pine has been attacked, any snapshot analysis is only an indication of minimum pine attack, not the final or maximum level of attack.

After MPB attack, residual trees have been shown to release well (Heath and Alfaro 1990, Veblen et al. 1991). There is no reason to believe the post MPB residual trees in the central BC interior will not release but the rates of release and subsequent stand dynamics are not understood (Veblen et al. 1991, Stockdale et al. 2004). As attacked trees die and more light reaches the forest floor, advanced regeneration (Cole and Amman 1980, Waring and Pitman 1984) and understory vegetation (Stone and

Wolfe 1996) should display enhanced growth rates. Again, the time frame and species relationships are poorly understood.

The objectives of this study are by age class, sub-zone and site series to i) document changes in stand characteristics of pine dominated stands following MPB attack and ii) assess the potential of stand development after MPB attack without management intervention.

2 Materials and Methods

In year one, age class 6 to 8 stands in the SBSdk (primarily located in the Lakes TSA) were selected on mesic and sub mesic sites as described by Rakochy (2005). In year two, candidate stands were identified off forest cover maps in the Prince George TSA. Reconnaissance was undertaken in age class 5 to 8 pine leading stands of the biogeoclimatic sub-zones SBSdw2 SBSdw3, and SBSmc3 southwest of Prince George to determine if they met the criteria for sampling. Sampling criteria in both years were: lodgepole pine leading; age class 6-8 or 5-8 (stands greater than 120 or 100 years old respectively); the above biogeoclimatic sub-zones; and less than 1 km from an access point. Stands were randomly selected in both years from the list of candidate stands for each age class and sampled.

2.1 Sampling

The sampling protocol commenced (POC) at least 100 m from polygon boundaries, roads or trails. Transects started at the POC and temporary sample plots (TSP) with a 5.64 m radius (100 m^2) were established every 50 m – 100 m along the transect line. Polygon (stand) size and shape dictated the distance and orientation among plots. A minimum of five plots were established in a polygon and 10 was the maximum. When atypical plot locations were encountered, such as areas with excessive wind throw or water, the plot was moved 25 m – 50 m along the transect line.

Forest cover polygon number, Global positioning system (GPS) location, site series, site index, and macro aspect were used to identify and characterize each TSP. Data collected in each TSP included crown closure using a spherical densitometer as described by Rakochy (2005), mature tree (diameter at breast height (dbh) at 1.37 m ≥ 7.5 cm) species, mature tree dbh, mature tree vigor or stage of MPB attack as described in Rakochy (2005), relative crown position (dominant, co-dominant, etc.), and wildlife-danger tree classification as detailed in Rakochy (2005). Tree cores from the site tree of each plot were used to confirm stand age and productivity (SI_{50}). Height was taken for the site tree in each plot. A smaller 3.99 m radius (50 m^2) plot with the same plot center as the larger mature tree plot was used to collect regeneration (natural or artificial) information in each TSP. Seedlings were regeneration with a height < 1.37 m while saplings had a dbh of < 7.5 cm and a height ≥ 1.37 m. Regeneration was assessed as recently dead, healthy and moribund – not likely to survive to the next stage (seedlings to saplings or saplings to poles). The species composition and percent cover of the shrub layer within the regeneration plot was described. A digital photograph of a randomly located 1 m X 1 m quadrat was taken to record the species composition of the forest floor. Species were identified in the office from the photograph.

In 2004, 49 stands and more than 300 TSP were sampled while in 2005 more than 70 stands and 250 TSP were sampled.

2.2 Data manipulation and Statistics

In year 1, six, 5-cm diameter classes were established: 10 (7.51-12.5 cm), 15 (12.51-17.5) etc. In year two, eight dbh classes with two different dbh ranges (2.5 and 5.0 cm) were established: 8.75 (7.51-10.0cm), 11.25 (10.01-12.5 cm); 13.75 (12.51-15.0), 17.5 (15.01-20.0), etc. The shorter ranges at the smaller dbh were established to assist in better estimating MPB attack on smaller trees.

Mature tree layer vigor and MPB attack (green, red, grey) and dbh class were summarized by species, polygon, age class and, in general, in the basic statistics module of SYSTAT Version 11 (2004). Regeneration layer mean dbh, height, and vigor were summarized by species, polygon, age class and overall in the basic statistics module of SYSTAT Version 11 (2004). Assessments of differences among

age class were done in the general linear model (GLM) and Tables modules of SYSTAT Version 11 (2004). Differences were considered significant at $\alpha = 0.05$.

3 Results and Discussion

3.1 Mountain pine beetle attack and the mature layer

Mountain pine beetle attack was not different among age classes in the SBSdw and SBSmc when looking at overall attack (P(F) = 0.4403) or attack on only pine trees (P(F) = 0.1885) (Table 1). However, in the SBSdk, MPB attack was different (P(F) = 0.0217) among age classes (Table 1). When only pine was considered in the SBSdk, attack rates increased marginally (Rakochy 2005). Overall attack rates were greater in the SBSdk but pine attack rates were greater in the SBSdw and SBSmc (Table 1). This may have occurred because the pre MPB SBSdk was essentially pure pine while the SBSdw and SBSmc was pine leading with large components of other species (Table 2).

At the landscape level, both overall and by age class the MPB attack reduced the pine component by half and doubled the spruce and Douglas-fir components in the SBSdw and SBSmc (Table 2). In the SBSdk, after MPB attack, the spruce component was increased threefold and the pine component was reduced by about 13 percent (Table 2).

Percentage of trees attacked (green, red, and grey) by the MPB in the SBSdk and SBSdw, SBSmc for all species and for pine only.

Condition*	Age class 5#	Age class 6	Age class 7	Age class 8
SBSdk				
All species	n/a	56.20	65.78	55.44
Pine only	n/a	58.62	69.70	62.61
SBSdw, mc				
All species	43.80	51.56	42.86	52.31
Pine only	70.16	80.22	81.80	83.60

*, dead trees from other causes are not included in the summary
#, age class 5 (81-100 years), age class 6 (101-120 years), age class 7 (121-140 years) and age class 8 (141-250 years)

Mature tree stocking after attack still exceeded minimum stocking levels (700 sph of which 600 sph must be primary species) in the SBSdw andSBSmc (BC Ministry of Forests 2000). If the remainder of the pine were attacked by the MPB, stocking would be marginally below minimum levels in age classes 5 and 8 and at or above minimums overall and in age classes 6 and 7 (Table 3). However, in the SBSdk age class 6 marginally met minimum stocking standards (as in the SBSdw) while the other two age classes and overall were not stocked (Table3). If the remainder of the pine is killed in the SBSdk by the MPB, the stands will be not satisfactorily stocked (50 – 140 sph). In all sub-zones, deciduous species contributed little to overall stocking.

General linear model (GLM) analysis for 2004 plots ($r^2 = 0.0277$) suggested MPB attack was different among age classes (P(F) = 0.0217) but not site series (dry, mesic) (P(F) = 0.7793) (not shown, Rakochy 2005). Similar analysis for 2005 plots ($r^2 = 0.2997$) demonstrated that MPB attack of pine was not different among age class or site series (dry, mesic, moist) but was significantly different (P(F) = 0.0003) among sub-zones: the SBSmc3 had less attack (Figure 1). This could be because of the reduced sample size or how the stands were located with respect to MPB progression across the landscape.

In the SBSdw and SBSmc, there was no difference among species' post MPB stocking by age class except for pine whose presence decreased (P(F) = 0.0160) as age class increased (Figure 2). There was no difference in sub-alpine fir or deciduous stocking for sub-zone or site series (Figures 3 & 4). However, Douglas-fir ($r^2 = 0.1873$, P(F) = 0.0244) and spruce ($r^2 = 0.2610$, P(F) = 0.0010) stocking was significantly different among sites series (Figure 4). Douglas-fir presence decreased as relative moisture increased and spruce presence increased as relative moisture increased. Douglas-fir was nearly significant for sub-zone (P(F) = 0.0594) (Figure 3). Its presence increased with relatively warmer temperature. Douglas-fir is not usually associated with the SBSmc3 (DeLong et al. 1993) and none was sampled. Post MPB pine

stocking was significantly (r^2 = 0.5001) different among sub-zones (P(F) = 0.0000) (Figure 3): increasing with relative moisture. Pine stocking was also significantly different (r^2 = 0.2644) among sub-zones

(P(F) = 0.0043) before MPB attack (not shown). As previously observed (Table 3), after MPB attack, the spruce component increased and the pine component decreased, creating mixed conifer stands in the SBSdw and SBSmc but in the SBSdk, the stands were still pure pine stands except for age class 8.

Table 2. Species composition (percent) overall and by age class before and after attack by the MPB in the SBSdw, mc and SBSdk.

Species*	Overall	Age class 5	Age class 6	Age class 7	Age class 8
Pre MPB					
SBSdw, mc					
Aspen	1.23	1.60	0.28	1.70	1.36
Sub-alpine fir	2.14	0.75	4.45	2.73	0.34
Birch	1.40	1.69	1.42	2.26	0
Douglas-fir	6.80	7.25	5.02	7.63	7.37
Pine	61.83	69.77	67.71	50.24	59.18
Spruce black	7.21	10.45	1.61	3.96	13.95
Spruce hybrid	19.38	8.47	19.51	31.48	17.80
SBSdk					
Aspen	0.16		0	0.18	0.19
Sub-alpine fir	0.11		0	0.13	0.10
Pine	92.98		95.87	94.37	88.54
Spruce hybrid	6.75		4.13	5.33	11.17
Post MPB					
SBSdw, mc					
Aspen	2.31	2.85	0.59	2.9	2.75
Sub-alpine fir	3.89	1.34	9.25	4.52	0.23
Birch	2.64	3.02	2.95	3.87	0
Douglas-fir	12.63	12.73	10.43	12.9	14.65
Pine	29.46	47.07	33.27	16.29	19.68
Spruce black	13.46	18.43	3.35	6.61	28.15
Spruce hybrid	35.62	14.57	40.16	52.9	34.55
SBSdk					
Aspen	0.45		0	0.52	0.57
Sub-alpine fir	0.30		0	0.39	0.29
Pine	81.24		91.00	84.41	68.38
Spruce hybrid	18.01		9.00	14.69	30.77

* dead trees from other causes are not included in the summary

Prior to attack, GLM analysis indicated mean dbh was significantly different (r^2 = 0.3173) among age classes (P(F) = 0.0000) and between site series (P(F) = 0.0000) in the SBSdk (Table 4). The largest trees were found in age class 8 and on mesic sites. Mountain pine beetle attack rates were slightly reduced in age class 8 stands (Rakochy 2005). In the SBSdw and SBSmc, mean dbh was different (r^2 = 0.1958) among sites series (P(F) = 0.0238) but was not different among age classes or sub-zones (Figure 5). Mean dbh increased as relative temperature increased and relative water decreased (with respect to the site series sampled). However after attack, dbh was significantly different (r^2 = 0.2306) among sub-zones (P(F) = 0.0386) and site series (P(F) = 0.0271) but not among age classes (Figures 5 & 6). Post MPB dbh increased where relative temperatures were warmer and was greatest on mesic sites.

Table 3. Post MPB stocking (sph) overall and by age class for pine, conifer and deciduous species in the SBSdw, mc and SBSdk.

Species	Overall	Age class 5	Age class 6	Age class 7	Age class 8
SBSdw, mc					
Pine	318	556	372	180	171
Conifer	707	556	707	850	675
Deciduous	53	69	40	75	24
Total	1078	1181	1119	1105	870
SBSdk					
Pine	442		600	415	336
Conifer	96		49	80	137
Deciduous	4		0	3	3
Total	542		649	498	476

Table 4. Pre MPB attack dbh ± SEM in the SBSdk by age class and site series.

Age class	6	SEM 6	7	SEM 7	8	SEM 8
dbh, cm	17.27	0.62	17.30	0.19	21.41	0.49
Site series	dry	SEM dry	mesic	SEM mesic		
dbh, cm	16.73	0.27	19.73	0.30		

Figure 1. Percent ± SEM of 2005 MPB attack in pine by site series (from left to right – dry, mesic, moist), sub-zone (SBSdw2, dw3, and mc3), and age class (5, 6, 7, and 8).

Figure 2. Stems per ha ± SEM in 2005 post MPB by age class (sub-zone and site series pooled) for sub-alpine fir (Bl). Douglas-fir (Fd), pine (Pl), hybrid and black spruce (Sx), and aspen and birch (Decid).

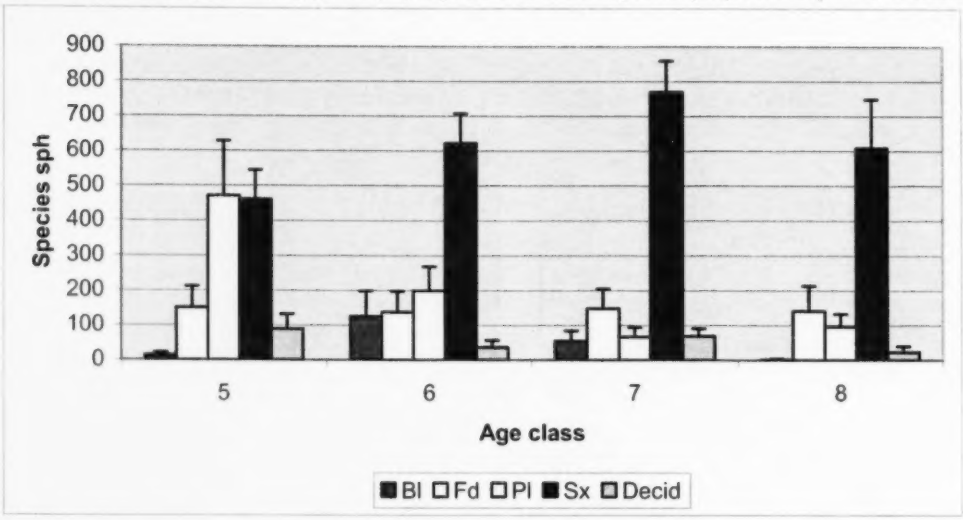
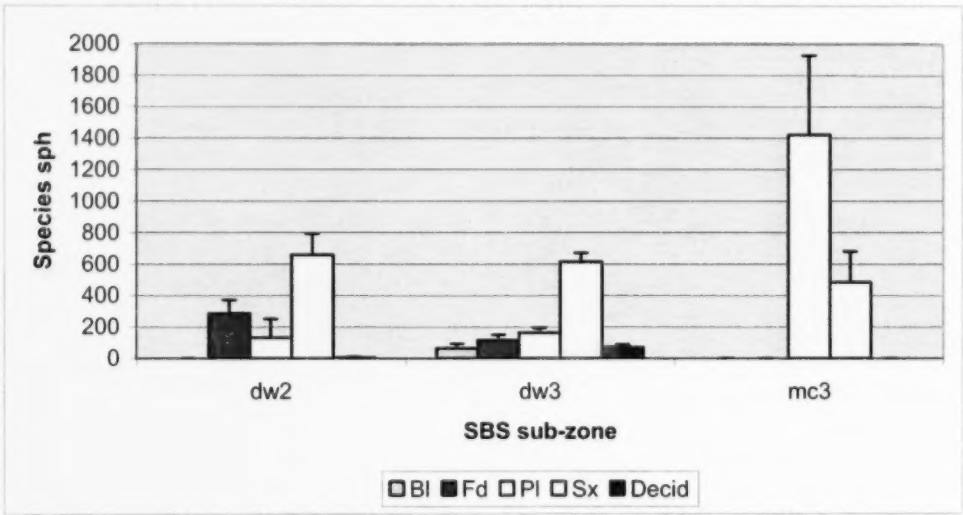


Figure 3. Stems per ha ± SEM in 2005 by SBS sub-zone (site series pooled) for sub-alpine fir (Bl). Douglas-fir (Fd), pine (Pl), hybrid and black spruce (Sx), and aspen and birch (Decid).



In both sample years, MPB attack was negatively correlated to stand density and positively correlated to dbh (equations 1 & 2). The former is surprising as it counters the rationale underlying 'beetle proofing' that wider spaced, vigorous, larger trees can better withstand MPB attack (Whitehead et al. 2004). The latter observation supports the link between MPB attack and tree size (Safranyik 1971, Shrimpton 1973, Shrimpton and Thomson 1985). When done as individual regressions, the negative or positive relationships between attack and sph or dbh did not change (not shown). Attack also increased by dbh class for both sample years (Figure 7). Attack reached maximum levels, ~80 percent, when dbh was greater than 20 cm but it still approached 10% – 15% at dbh less than 12.5 cm. This observation supports that of Cole and Amman (1969, 1980) where the average dbh of trees attacked decrease with the length of time the MPB has been in the stand. Whether there is adequate phloem for the MPB to successfully reproduce (Safranyik 1971, Shrimpton 1973, Shrimpton and Thomson 1985) in these small trees is not known.

Figure 4. Stems per ha ± SEM in 2005 by site series (sub-zone and age class pooled) for sub-alpine fir (Bl). Douglas-fir (Fd), pine (Pl), hybrid and black spruce (Sx), and aspen and birch (Decid).

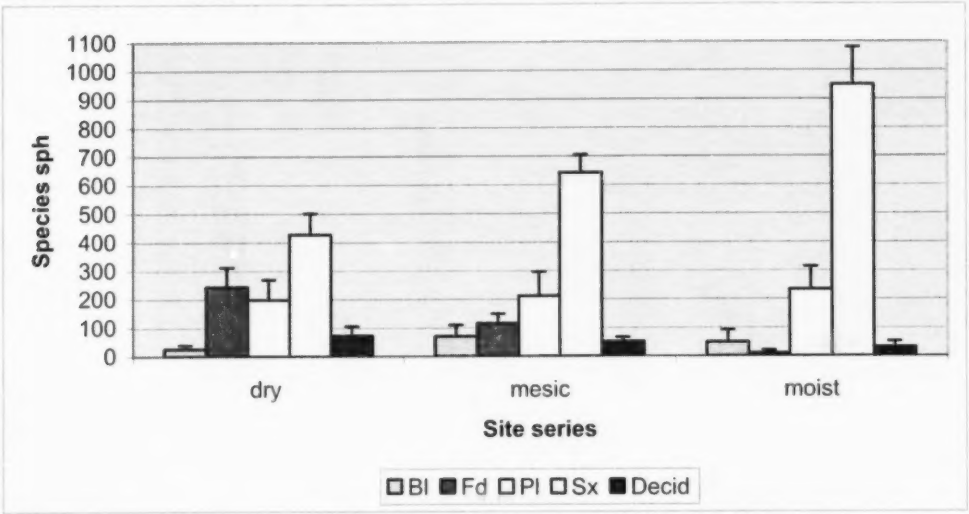
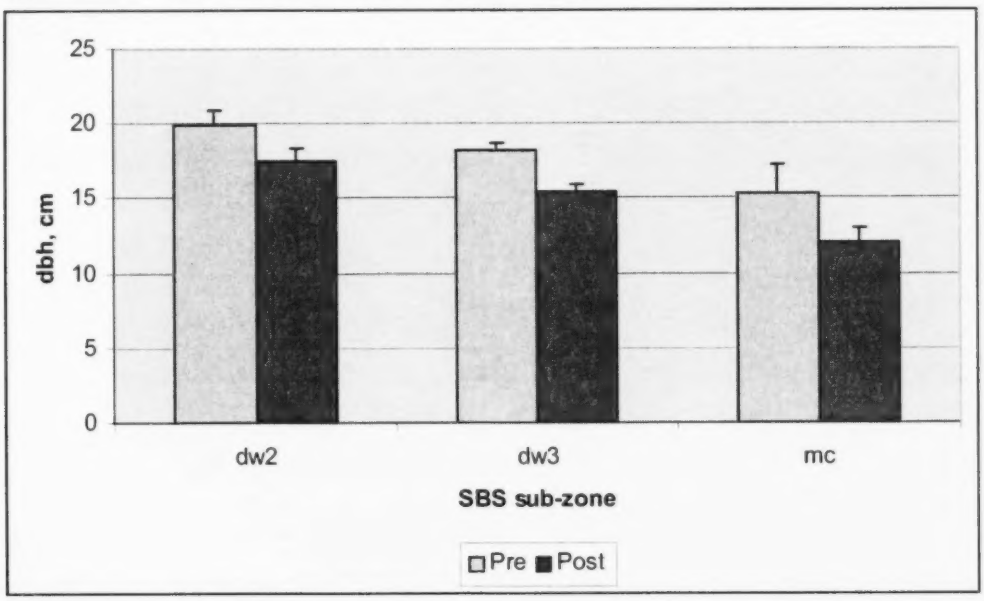


Figure 5. Mean 2005 dbh ± SEM pre and post MPB by sub-zone (pool age and site series).



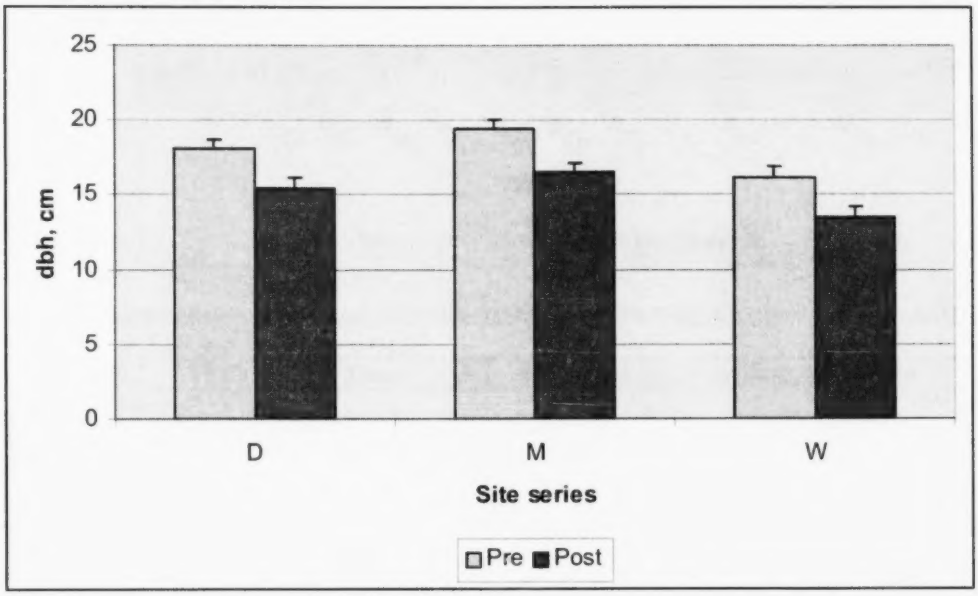
(Eqn 1) Attack in SBSdk = 53.76 – (0.0093*sph) + (1.615*dbh) $r^2 = 0.2817$

(Eqn 2) Attack in SBSdw, mc = 97.13 – (0.0185*sph) + (0.4195*dbh) $r^2 = 0.3841$

The observed attack rates in both years are consistent with other studies (Cole and Amman 1980, Hawkes et al. 2004). As MPB attack is episodic or in waves (Cole and Amman 1969, 1980), the snapshot of attack we are presenting today could increase if these stands were resampled. The difference in the attack rates among the sub-zones is also a function of time since the outbreak of the epidemic and the beetle population. The outbreak is older in the SBSdk than in the SBSdw and SBSmc (Rakochy 2005)

and its duration is longer than described for the western USA (Cole and Amman 1980). The number of surviving stems in the SBSdk is lower (542 sph) than reported by Hawkes et al. 2004) in areas adjacent to the SBSdk (645sph) while in the SBSdw and SBSmc it is greater (1078 sph). The residual tree (pine) numbers may reflect the 'stage' the epidemic is at in a particular sub-zone. It is projected that mortality will not decrease to endemic levels until about 2020 (Eng et al. 2005). The final results of this epidemic will not be known until the beetle is/has stopped: either by extreme cold (Cayer 1988) or a lack of host (Wood and Unger 1996, Eng et al. 2004).

Figure 6. Mean 2005 dbh ± SEM pre and post MPB by site series (D – dry, M – mesic, W- moist) (age class and sub-zone pooled).



3.2 Regeneration layer and post mountain pine beetle stocking

Less than 5% of the 350+ regeneration plots in the SBSdw and SBSmc were void of regeneration: *c.f.* Rakochy (2005) who found about 40% of 300 plots void of regeneration in the SBSdk. On average, there were 328 sph of healthy regeneration in the SBSdk; about 200 sph were seedlings and 128 were saplings (Rakochy 2005). Of the healthy regeneration in the SBSdk, 45.7% was pine, 38.4% spruce, 10.1% sub-alpine fir and 5.3% aspen (Rakochy 2005). There was significantly more regeneration in the SBSdw and SBSmc (2005) than in the SBSdk: 2003 sph of healthy regeneration of which 1173 sph were seedlings and 830 sph were saplings (Table 5). Hawkes et al. (2005) have attributed high levels of pine regeneration to less productive sites. However, the SBSdk is less productive than the other sub-zones (DeLong et al. 1993) which had more regeneration. There was no difference (r^2 = 0.1060) in the SBSdw, moisture content (mc) among age class, sub-zone or site series for regeneration. Generally 50% or more of the regeneration was spruce and less than 20% was pine (Figure 8): *c.f.* the SBSdk where almost 50% of the regeneration was pine. If all of the pine were removed from both the mature and regeneration layers, the SBSdk is not satisfactorily stocked but the SBSdw and SBSmc is satisfactorily stocked (Table 6). This indicates that post MPB stand management will be at least sub-zone specific.

Figure 7. Mean percent of MPB attack and healthy trees (OK) by dbh class in 2004 (SBSdk) and 2005 (SBSdw).

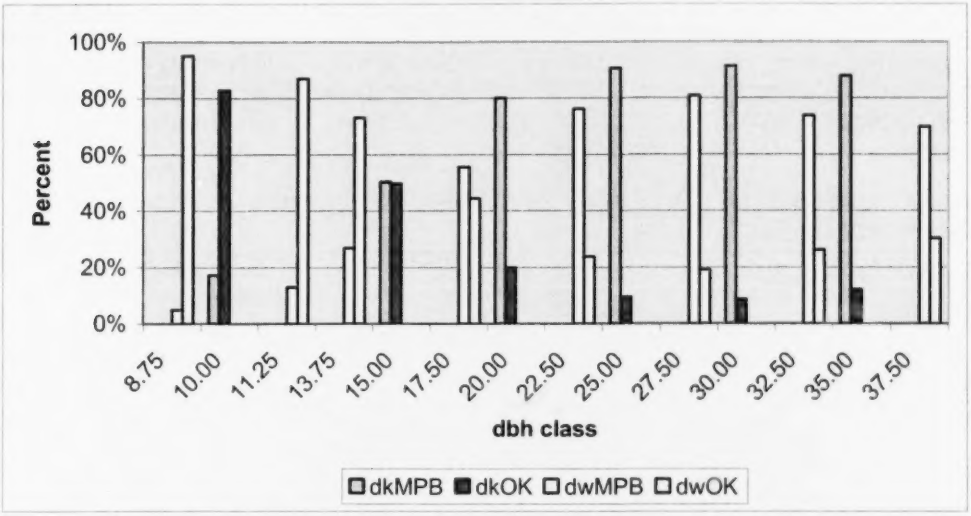


Table 5. Contribution to stocking (sph) in the SBSdw, mc and SBSdk by the regeneration layer and the mature layer.

Year	Overall	Age class 5	Age class 6	Age class 7	Age class 8
2005 (SBSdw, mc)					
Mature	1078	1181	1119	1105	870
Regeneration	2003	2407	1957	2001	1601
Total	3081	3588	3076	3106	2471
2004 (SBSdk)					
Mature	542		649	498	476
Regeneration	328		232	359	338
Total	870		881	857	814

Mean seedling height was 0.74 ± .01m and mean sapling height and dbh respectively were 3.28 ± 0.11m and 2.9 ± 0.11cm in the SBSdk (Rakochy 2005). Not only was there more regeneration in the SBSdw and SBSmc, saplings were taller with greater dbh (4.60 ± .07m, 3.63 ± .04cm) and seedlings were shorter (0.55 ± .011m). The sapling regeneration is of significant size in both sample years and should contribute to future stand structure. The present basal area of saplings in the SBSdk is 0.085 m^2 and in the SBSdw and SBSmc it is 0.859 m^2. Based on TIPSY projections using existing stocking and site indices of 15 and 18, in the SBSdk, it would take about 10 to 15 years to attain this basal area (not shown). The basal area in the SBSdw and SBSmc would take 15 to 20 years to attain at the same site indices (not shown). Harvesting the stand types, particularly in the SBSdw and SBSmc would move any harvest 20 years further into the future than if the stand were left to develop from today's starting point.

Figure 8. Percent regeneration (seedling and sapling) in 2005 by age class (sub-zone and site series pooled) and species.

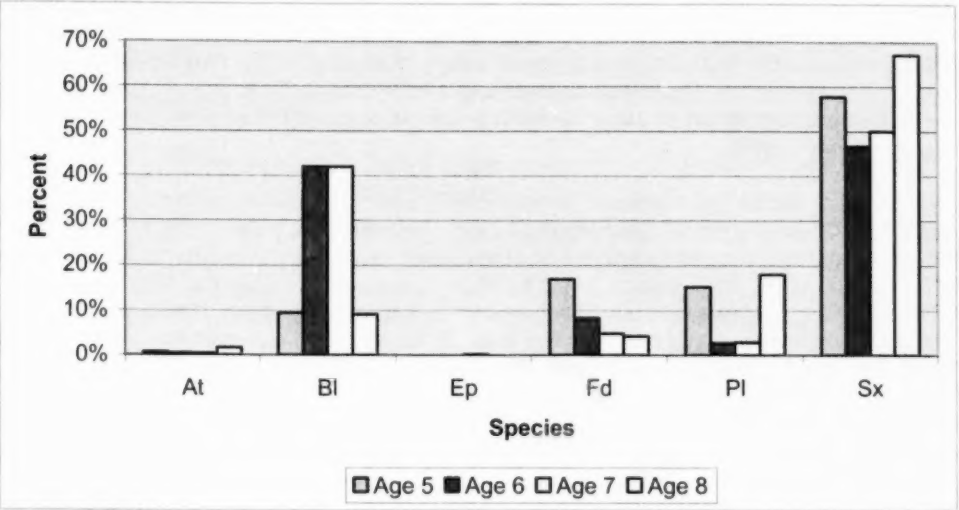


Table 6. Contribution to stocking (sph) in the SBSdw, mc and SBSdk with pine removed by the regeneration layer and the mature layer.

Year	Overall	Age class 5	Age class 6	Age class 7	Age class 8
2005 (SBSdw, mc)					
Mature	760	625	747	925	699
Regeneration	1717	2063	1677	1715	1372
Total	2477	2688	2424	2630	2071
2004 (SBSdk)					
Mature	100		49	83	140
Regeneration	150		106	164	154
Total	250		155	247	294

The SBSdw and SBSmc were well stocked after MPB attack while the SBSdk was not (Tables 5 & 6) particularly if there is more mortality in the mature (pine) layer. There is sufficient regeneration in the SBSdw and SBSmc to consider a stand fully stocked (BC Ministry of Forests 2000) even if all the healthy pine were to die. Alone, there is not sufficient regeneration in the SBSdk to stock a stand if the pine were to die. Even without removing all the pine, SBSdw and SBsmc stands are heterogeneous, suggesting enhanced ability to withstand future MPB attacks. The MPB has created uneven aged or complex stands (Oliver and Larson 1996) in the age classes sampled. Competition between seedlings and shrub and herbaceous layers should be reduced on drier site series (Banner et al. 1993). This suggests the seedling component should release well, except, perhaps, on the moist site series. Kovacic et al. (1985) suggested it may take up to 10 years for the stand environment to be fully favorable for seedling release. It must be kept in mind that an environment favorable for seedling growth is also one favorable for the growth of competing species (McCambridge et al. 1982).

3.3 Significance of findings

The overall impact or severity of the MPB attack was much greater in the SBSdk (2204) than in stands sampled in 2005. This may reflect the greater proportion of pine, almost pure pine stands, in this sub-zone. Based on Eng et al. (2005) model, Rakochy (2005) hypothesized the MPB epidemic was waning in the SBSdk. If this is the case, the percentage of MPB attack will probably not change and overall, the stand will be satisfactorily stocked between the mature and the regeneration layers. It must be kept in mind that 40% of the plots were void of regeneration. As a result, some stands would be marginally stocked and others would be well stocked. However if the MPB epidemic is not waning, it may be prudent

to carefully harvest the age class 6 and 7 stands, leaving all mature trees of non pine species and the most vigorous of the saplings. Age class 8 stands may be starting to 'break up' and would need to be treated on a case by case basis. Mixed species planting after logging could be done at or near minimum levels (700 sph). If any type of enhanced planting is to be done, the stands likely have to be logged or at a minimum have the danger trees felled to ensure worker safety (Rakochy 2005). This would ensure stocked stands with species diversity: insurance against future MPB attack. Thus, the best management approach for the SBSdk will depend on whether the MPB epidemic is waning or whether restoration activities are required (Parfitt 2005).

In the SBSdw and SBSmc, stands had significant levels of MPB attack. Because these sub-zones have a more diverse forest cover than the SBSdk (Banner et al. 1993, DeLong et al. 1993), after MPB attack, there were significant quantities of spruce (hybrid and black) and Douglas-fir in the stands. Even if all the mature pine is killed by the MPB, these stands would be at or near stocking minimums (BC Ministry of Forests 2000). The regeneration layer was also diverse, probably as a result of the diverse overstory. It also has very high stocking levels whether pine was or was not counted. No management intervention in stands of these sub-zones will result in uneven aged, complex stands which could be suitable for some harvest in 20 to 60 years, depending on present species composition and structure. Waiting at least 20 years provides an opportunity for the regeneration to release and be well established so that it can be left when the mature layer is removed. Potentially, these stands will be able to address one of the major concerns surrounding MPB attack: the mid term timber supply (Eng et al. 2005, Pousette 2006). Maintaining these older age class stands on the landscape will also help to maintain structural and age diversity and thereby minimize deviation from historic range of variation (Eng 2004). A potential implication of addressing the epidemic by logging is that large areas of age class 1 will be created. In 80 – 100 years, the landscape again would have an overabundance of suitable MPB host.

MPB attack rates were reduced as stand density increased. We cannot directly determine whether this is a density effect (more trees – less MPB attack) or a dbh effect (more trees – smaller dbh). The same response has been observed between pre-commercially spaced and unmanaged, age class 3, fire origin stands in the SBSdw3 (Hawkins unpublished data). If this is purely an MPB attack response to dbh as the literature suggests (Safranyik 1971, Shrimpton 1973, Shrimpton and Thomson 1985), then vigorous, widely spaced, young (late age class1 and age class 2) stands could be at a much greater risk to MPB attack than is currently thought (Eng et al. 2004, 2005).

4 Conclusions

The impact of MPB attack depended, in large part, to the stands' species composition prior to attack. Pure, or nearly pure pine stands had mature tree stocking at or near minimums after attack. If the MPB continued to attack these stands they would go to being not satisfactorily stocked. On the other hand, pine leading stands with significant components of other species were still well stocked after MPB attack, and even if the MPB continued to remove pine they would be satisfactorily stocked.

There was significantly less regeneration in the pure pine stands (SBSdk) than in the pine leading stands (SBSdw2, SBSdw3, SBSmc3). As a result, pure pine stands had only enough regeneration that when it was added to the mature layer, it brought them to a stocked level. Pine leading stands had considerable regeneration, 2000 sph on average. This meant they were fully stocked by the regeneration layer alone.

Without management intervention, the stands in the SBSdk at best will be marginally stocked and will likely contribute little to the mid term timber supply. Depending on management objectives, a restoration effort is likely warranted in this sub-zone. Conversely, the stands of the SBSdw and SBSmc are stocked both in the mature layer and the regeneration layer. With careful logging, these stands could provide timber both in the mid and longer terms.

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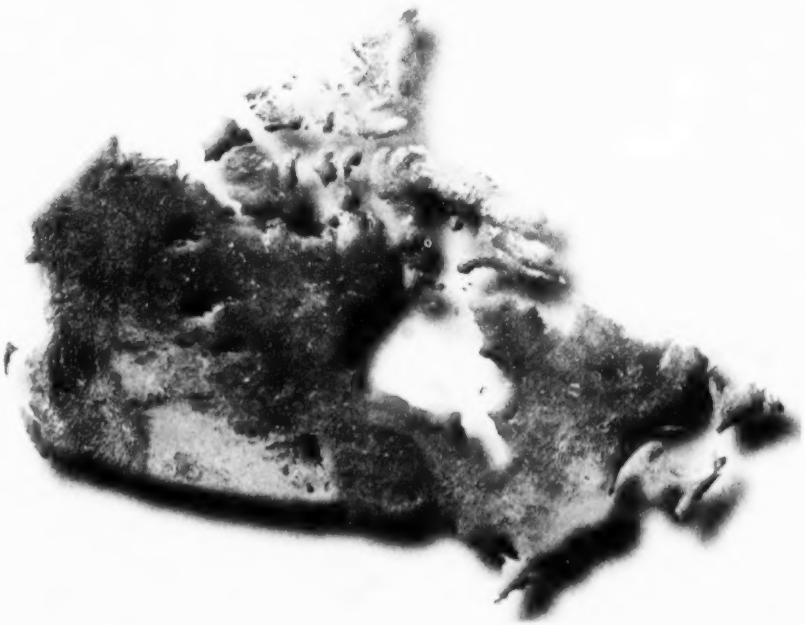

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